

Distributed Algorithm for Emergency Evacuation

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Distributed Emergency Evacuation

- An application for Specknets
 - Fire / Smoke Detection in buildings
 - Distributed Algorithm for directing evacuating persons via *safest* exit paths
- Considered
 - Algorithm to find safe exit paths
- Not Considered
 - Hazard Detection
 - How to direct people



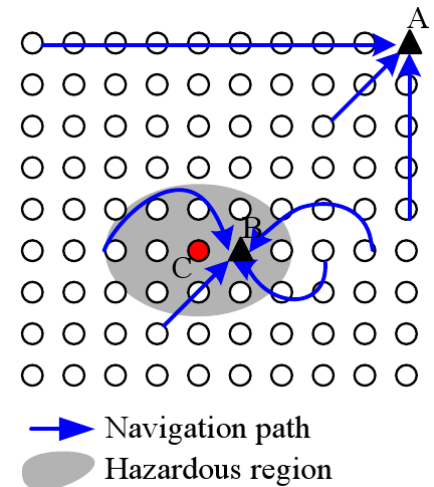
Hazard Avoidance using Sensor Networks

Hazard Avoidance & Sensor Networks (1)

- Potential Fields

- Li et al, “*Distributed Algorithm For Guided Navigation Across A Sensor Network*”

- On grid distributed networks
 - Routed based on ‘*potential*’ of locations
 - Potential is distance from target node
 - Hazards Raise potential



Hazard Avoidance & Sensor Networks (2)

- Altitude / Contour Map

- Tseng et al, “Wireless Sensor Networks for Emergency Navigation” && “Emergency guiding and monitoring applications in indoor 3d environments by wireless sensor networks”

- Grid deployed networks with pre-computed paths to target

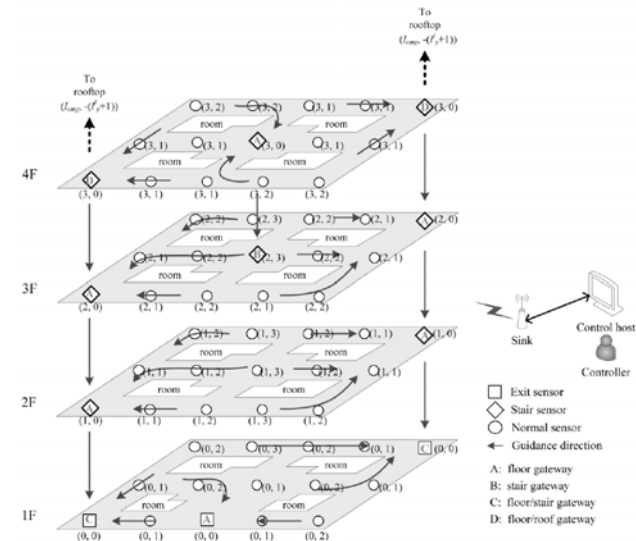
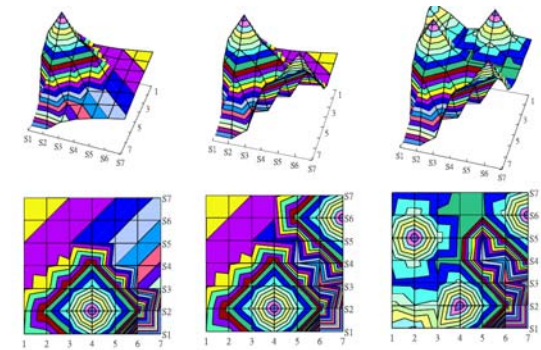
- Hazards raise *altitude* in *hazard region*

- Requires arbitrary *Emergency Altitude* and *Region Size*

- Expanded to 3D Buildings

- Requires Specialist Nodes for stairs

- Floors are independent



Modelling techniques of Fire / Smoke Spread.

- “*Detector Response Model*” : predicts the times at which fire detection equipment is triggered in response to a fire
- Many models of occupant Egress
- Danger of a fire may be through smoke or flames.
 - We describe the spread of the *hazard*, i.e. conditions that are hazardous to occupants

Evacuation Algorithm



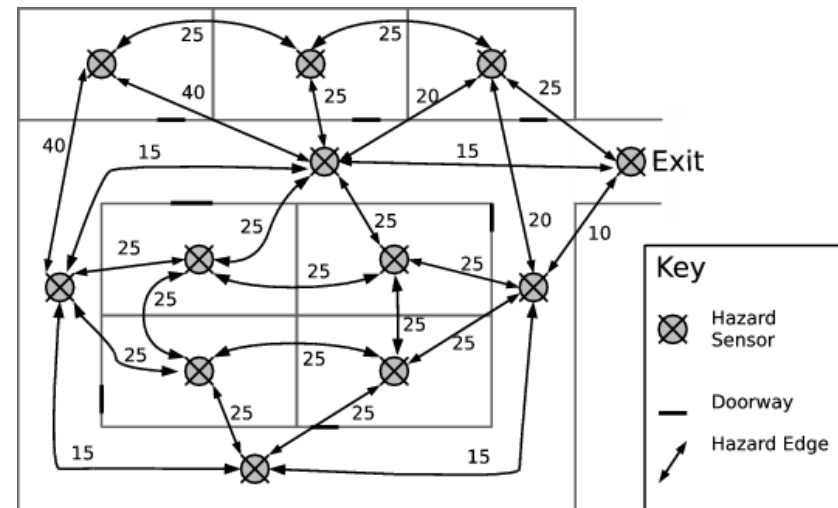
Algorithm Model

- An algorithm to direct evacuees via safest paths through arbitrarily complex building layouts in emergencies.
- Sensors are deployed at predetermined locations.
- Graphs of hazard spread and occupant egress formed over those locations



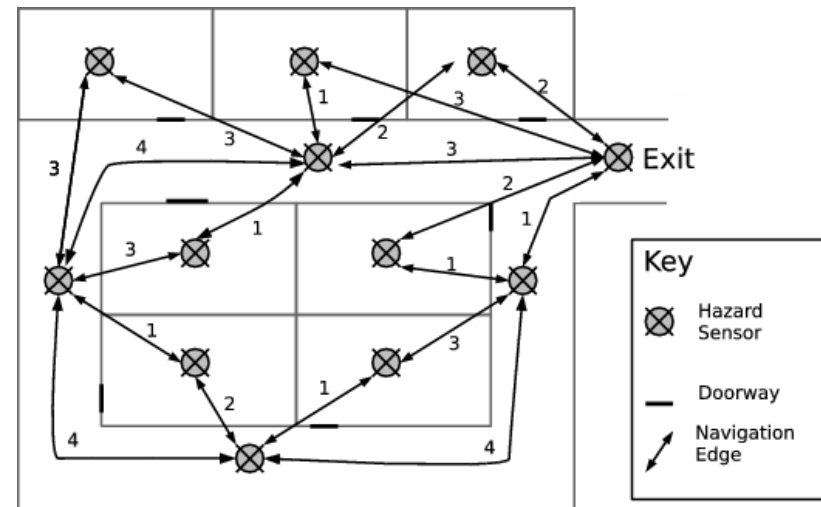
Hazard Model

- A model of the spread of a hazard throughout the building.
 - Represented as a graph
 - Sensor Locations are nodes
 - Edges are paths by which the hazard may spread
 - Weights are the time taken for a hazard to spread via the edge.



Egress Model

- A model of how people may move throughout the building.
 - Represented as a graph
 - Sensor Locations are nodes
 - Edges are routes by which evacuating people may travel
 - Weights are the time taken for a person to travel the edge.



Hazard Spread Times

- Hazard Weight, $F_{u,v}$: the time taken for a hazard to spread from u to v
- Hazard Time for node v , H_v : the time until the location of v is hazardous

$$H_v = \text{Min}_{p \in P, p = \langle p_1, p_2, \dots, p_n = v \rangle} \left(\sum_{i=1}^{n-1} F_{p, p_{i+1}} \right)$$

where P is the set of all paths

Exit Path Safety

- Navigation Weight, $R_{u,v}$: the time taken for a person to travel the route u to v
- Safety of an exit path p , $S(p)$: the minimum time difference between the hazard reaching a node on the path and an evacuee starting at the beginning of the path reaching the node



Safety Computation

- Inductively Computable from the exit:

- Safety from the exit is the hazard time of the exit :

$$S(\langle v_{exit} \rangle) = F_{v_{exit}}$$

- From the path :

$$p = \langle v_i, v_{i+1}, \dots, v_{exit} \rangle$$

- We have the path :

$$p' = \langle v_{i-1}, v_i, v_{i+1}, \dots, v_{exit} \rangle$$

- Where :

$$S(p') = \min(S(p) - R_{v_{i-1}, v_i}, H_{v_{i-1}})$$

- Node Safety :

$$S_v = \max_{p \in P} S(p) \quad \text{where } P \text{ is the set of all paths}$$

Simple Approach

- A simple approach:
 - (1) A fire is detected
 - (2) Calculate all hazard times and propagate them to all nodes
 - (3) Calculate Exit paths and propagate to all nodes
- Requires Centralized controller or a bound on the time at which stage 2 is completed before 3 can take place

Distributed Algorithm (1)

- Fully distribute the algorithm:
 - Each node computes its own state with estimates
 - h_v : hazard time estimate
 - s_v : exit path safety estimate
 - $successor_v$: the next node on the exit path
 - Graph information distributed in small amounts across all nodes
 - Edges connecting the nodes to its neighbours on the hazard and navigation graphs
 - The currently estimated safety of each neighbour in a table.

T_v^u : the table entry of node v for node u

Distributed Algorithm (2)

- Initialization:
 - Each node sets its estimates so that :

$$h_v := \infty$$

$$s_v := -\infty$$

$$successor_v := \perp$$

- Emergency detection:
 - Set : $h_v := 0$
 - Transmit : $\{ID_v, h_v, s_v\}$

Distributed Algorithm (3)

- Nodes react to radio transmissions.
 - On receiving the packet $\{ID_u, h_u, s_u\}$, node v follows the rules below:

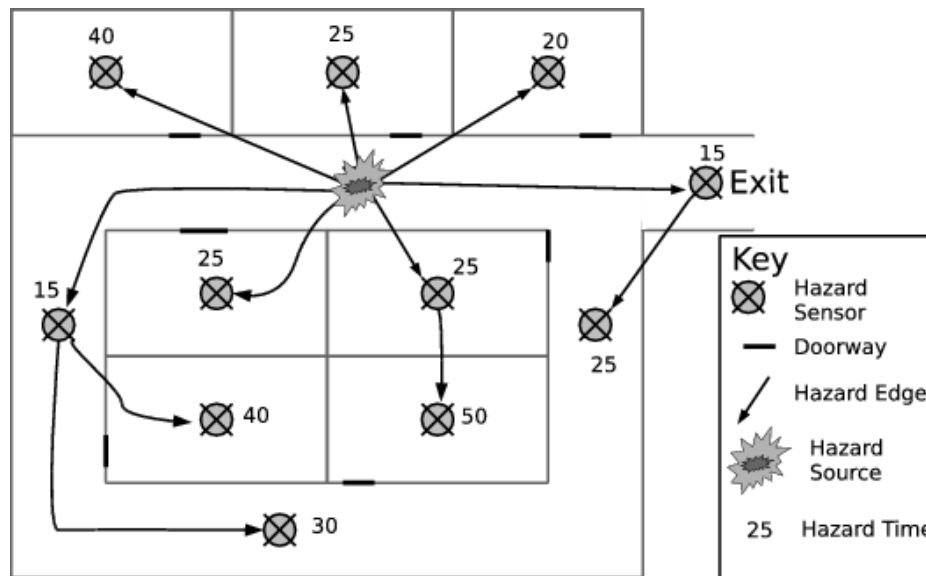
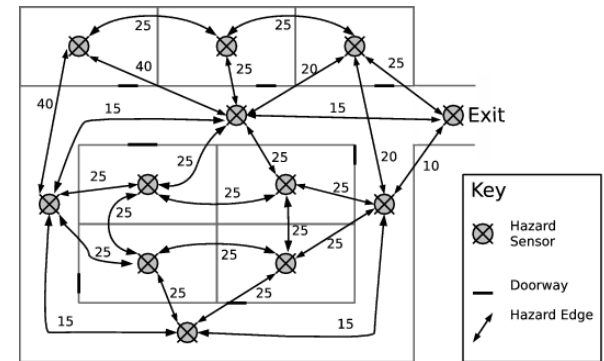
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1:  $T_v^u := s_u$ 
2: if  $h_u + F_{u,v} < h_v$  then
3:    $h_v := h_u + F_{u,v}$ 
4: end if
5: if  $v = v_{Exit}$  then
6:    $s_v := h_v$ 
7: else
8:    $s_v := \min(h_v, \text{Max}_{w \in V}(T_v^w - R_{v,w}))$ 
9:    $successor_v$  is set to be any neighbouring node  $w$  for
     which  $T_v^w - R_{v,w} \geq (T_v^x - R_{v,x}) \forall x \in V$ 
10: end if
11: if  $s_v$  or  $h_v$  has been changed then
12:   transmit  $\{ID_v, h_v, s_v\}$  to all neighbours
13: end if
```



An Example (1)

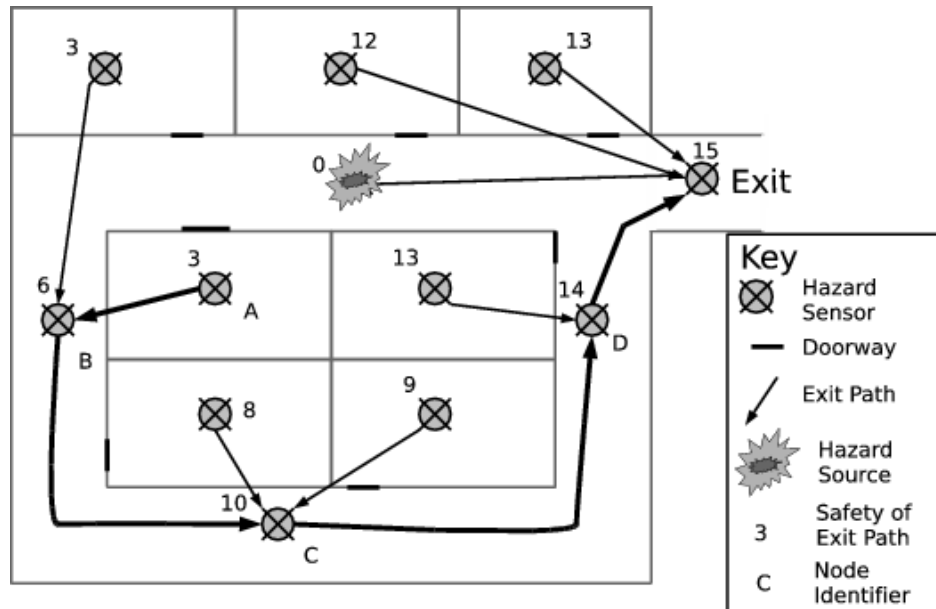
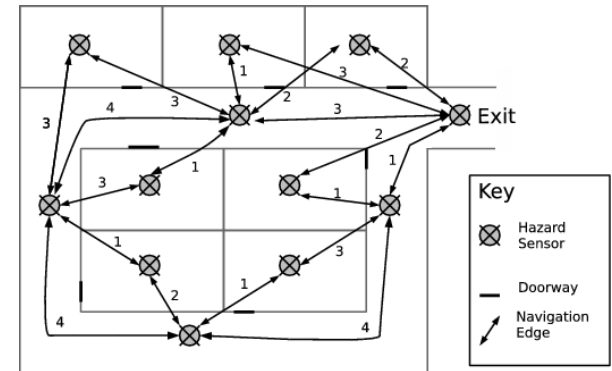
- Computed Hazard Times:

- Smallest weighted path from hazard to each node



An Example (2)

- Exit Path Safeties:



An Example (3)

- The safety of the path from node A:

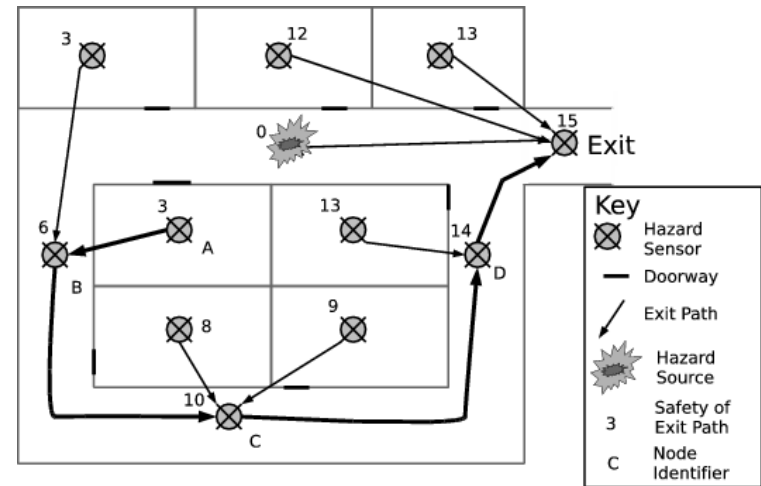
$$S(\langle v_{exit} \rangle) = H_{v_{exit}} = 15,$$

$$S(\langle v_D, v_{exit} \rangle) = \min(H_{v_D}, S(\langle v_{exit} \rangle) - R_{v_D, v_{exit}}) = \min(25, 15 - 1) = 14,$$

$$S(\langle v_C, v_D, v_{exit} \rangle) = \min(H_{v_C}, S(\langle v_D, v_{exit} \rangle) - R_{v_C, v_D}) = \min(30, 14 - 4) = 10,$$

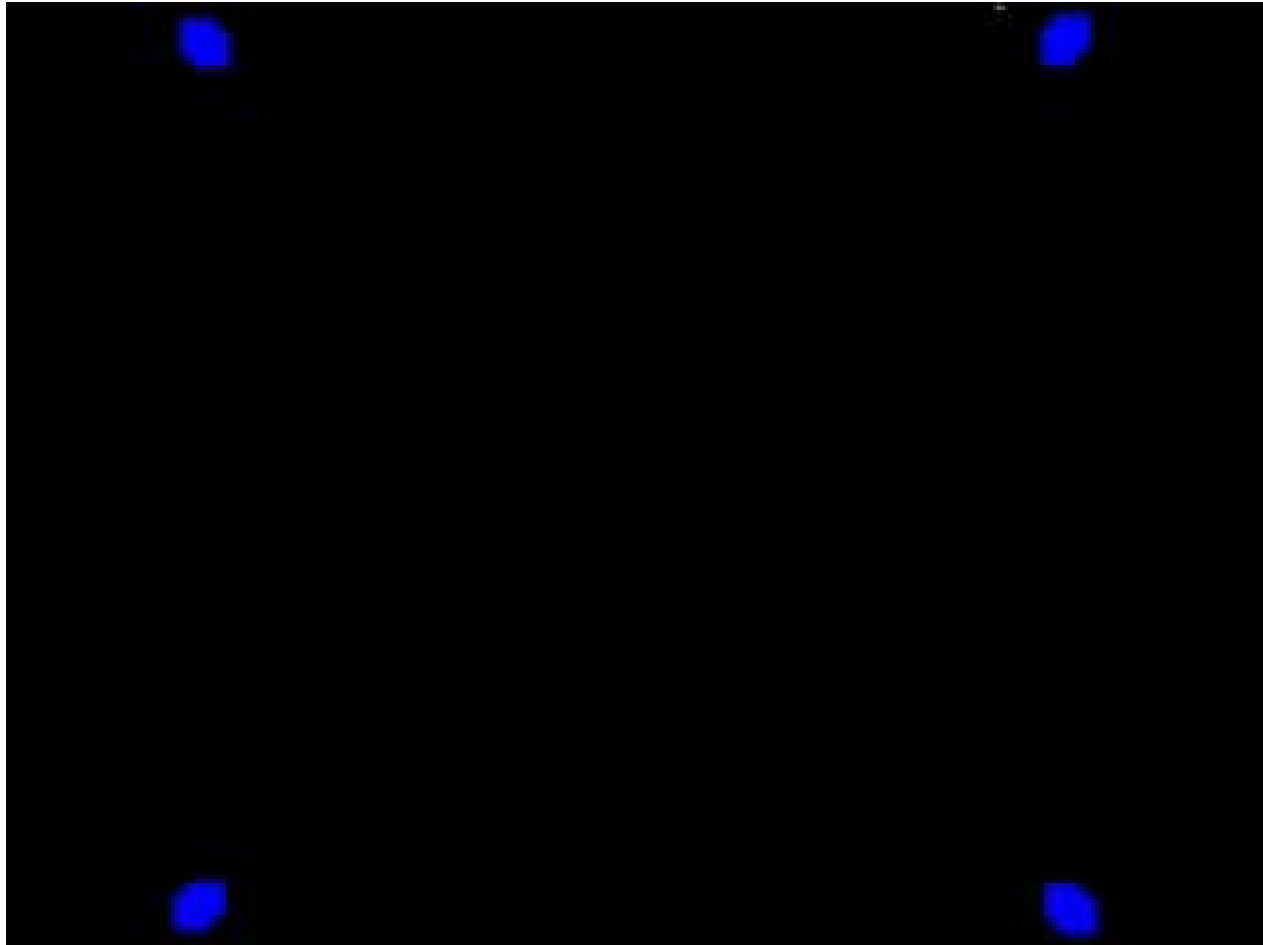
$$S(\langle v_B, v_C, v_D, v_{exit} \rangle) = \min(H_{v_B}, S(\langle v_C, v_D, v_{exit} \rangle) - R_{v_B, v_C}) = \min(15, 10 - 4) = 6,$$

$$S(\langle v_A, v_B, v_C, v_D, v_{exit} \rangle) = \min(H_{v_A}, S(\langle v_B, v_C, v_D, v_{exit} \rangle) - R_{v_A, v_B}) = \min(25, 6 - 3) = 3.$$



- The evacuee starting at A is estimated to reach the exist 3 time units before the hazard

Visualisation of a Grid Layout



Idealised Scenario

- Modelled situation is ideal and limited
 - Hazards spread at expected rates
 - No reaction to extinguished sources
 - Node failure may have disastrous consequences



(Some) Real Considerations

- Hazard may spread at rates different to that expected
 - Faster appears as more sources
 - Slower spread may allow for alternative paths
- Fires may be extinguished
 - May allow for alternative paths
- Communication must be bounded to ensure settling time
- Node failure is very likely
 - Appears as more sources for safety



Extended Adaptable Algorithm



Adaptive Algorithm (1)

- 1) if $(FS_u \in C_v) \wedge (SN_{FS_u} \leq C_v^{SN_u})$ then
 $T_v^u := \{ID_u, F_{u,v}, R_{v,u}, \perp, \infty, -\infty, \perp, 0\}$
- 2) if $X_{ID}^u \neq \perp$ then
 - a) if $(FS_w = X_{ID}^u) \wedge (SN_{FS_w} < X_{SN}^u) \forall w \in V$ then
 $T_v^w := \{ID_w, F_{w,v}, R_{v,w}, \perp, \infty, -\infty, \perp, 0\}$
 - b) if $(FS_v = X_{ID}^u) \wedge (SN_{FS_v} < X_{SN}^u)$ then
add $\{FS_v, X_{SN}^u\}$ to C_v
 $X_{ID}^v := X_{ID}^u$
 $X_{SN}^v := X_{SN}^u$
 - c) else if $FS_v = ID_v$ then
add $\{X_{ID}^u, X_{SN}^u\}$ to C_v
 $X_{ID}^v := X_{ID}^u$
 $X_{SN}^v := X_{SN}^u$
- 3) else
if $(ID_u = FS_v) \wedge (h_u > (h_u \in T_v^u))$
 - a) if $(FS_w = ID_u) \wedge (SN_{FS_w} < SN_u) \forall w \in V$ then
 $T_v^w := \{ID_w, F_{w,v}, R_{v,w}, \perp, \infty, -\infty, \perp, 0\}$
 - b) add $\{ID_u, SN_u\}$ to C_v
 $X_{ID}^v := ID_u$
 $X_{SN}^v := SN_u$

Adaptive Algorithm (2)

- 4) $h_v := \text{Min}_{w \in V}(h_w + F_{w,v})$
 $FS_v := FS_w$
- 5) if $v = v_{Exit}$ then
 $s_v := h_v$
else
 $s_v := \min(h_v, \text{Max}_{w \in V}(T_v^w - R_{v,w}))$
 $successor_v$ is set to be any neighbouring node for which
 $T_v^w - R_{v,w} \geq (T_v^x - R_{v,x}) \forall x \in V$
- 6) If s_v or h_v or FS_v has been changed transmit $\{ID_v, h_v, s_v, FS_v, SN_{FS_v}\}$ to all neighbours.
- 7) If $X_{ID}^v \neq \perp$ transmit $\{X_{ID}^v, X_{SN}^v\}$ to all neighbours.

- A few additions and complications.
 - Full explanation for another day...



Adaptations

- Reacts to extinguished sources.
 - Paths are found that pass through previously hazardous areas to avoid currently active hazards
- Times/Safeties are computed with spread of actual hazards with minimal overhead
- Communication has probability of being bounded.
 - In relation to an available cache of unexpected events



Simulation Demo

Future Developments

- An adaptive scheme for rapidly spreading hazards and node failures.
- Consideration of different hazardous conditions
- Communications / Memory Usage trade
- Specialised Network Protocols



Questions?

